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Microminiature Packaging of Electronic Circuits (U)

N. J. Doctor

E. M. Davies

30 June 1958



DIAMOND ORDNANCE FUZE LABORATORIES
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MICROMINIATURE PACKAGING OF ELECTRONIC CIRCUITS (U)

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FOR THE COMMANDER
Approved By


for

H. P. Kolmus
Chief, Laboratory 50



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ABSTRACT (U)

DOFL has for many years been engaged in developing techniques in packaging miniature electronic circuits, using small commercial parts, printed parts, printed wiring, and uncased parts. A working group on microminiaturization has been active since May, 1957. In a joint effort by members specializing in compact circuit design, miniature parts development, and high-density packaging techniques, a binary counter stage was packaged, using commercial microminiature component parts and etched wiring techniques; densities of 140 components/cu. in. were achieved in operating circuits. Subsequently, utilizing printed components and wiring, and uncased transistors and diodes, densities of 2800 components/cu. in. were achieved in laboratory models of the same counter.

Future work in DOFL will include investigations of: (1) the relationship between the geometry of minute printed resistors and their resistance value, (2) dip soldering techniques applicable to the preparation of microminiature electronic assemblies, (3) fabrication techniques for producing flat, minimum-volume, inductive components, and (4) interconnection techniques for connecting microminiature stages into larger assemblies with minimum expenditure of volume.

INTRODUCTION

With the growing complexity of military electronic equipment, and the desire to fuze smaller and smaller munitions, it is only a matter of time until the fuze engineer will begin clamoring for microminiature components and circuit packages. Sensing this trend, DOFL, in 1957, initiated a work group on microminiaturization.

This report summarizes techniques of miniaturization developed at DOFL in which printed circuits, small commercial parts, printed parts, uncased parts and high-density packaging methods are used. A binary counter circuit is used to illustrate the progressive reductions accomplished. This circuit was chosen for several reasons: (1) it was a relatively noncritical circuit, i. e. extremely close component tolerances did not have to be held, (2) it was a highly repetitive digital computer circuit, a type which would actually be produced in sizeable quantities, and (3) it was unclassified, and therefore, would permit discussion of the work with other agencies and laboratories engaged in related work in this field.

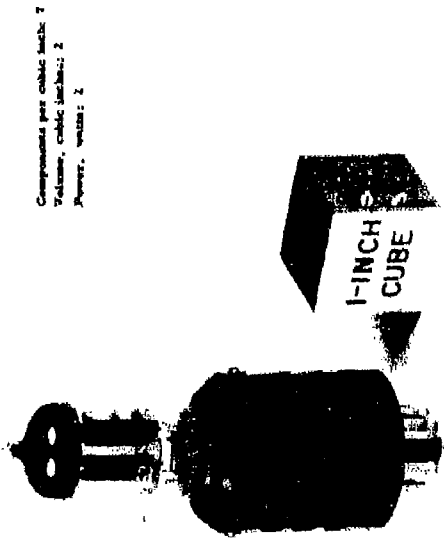
Figure 1 shows a vacuum tube binary counter module. This design was popular several years ago and was employed in many computers. The particular unit shown was marketed by the General Electric Co. Alongside of it is shown a one-inch cube which will be used as a size reference in many of the subsequent figures. This vacuum tube binary counter occupies a volume of about 2 cubic inches and requires 2 watts of power.

MINIATURIZATION BY COMPONENTS AND TECHNIQUES KNOWN OR DEVELOPED PRIOR TO 1955

Initially, a degree of miniaturization of the binary counter was accomplished using conventional components and techniques. For example, it was well known that savings in power had been effected by the use of transistors in many circuits previously considered exclusively in the vacuum-tube domain. By coupling the transistorized circuit with conventional etched wiring, the package shown in figure 2 was obtained 1/. This circuit performed the same function as the previous one and yet required only 1/200 the power and occupied only one-half the volume.

Before proceeding further, a brief explanation of the steps of preparation of an etched wiring board 2/ is in order. Figure 3a shows the base for an etched wiring assembly; it is a plastic insulating laminate on the surface of which is bonded a thin copper foil. The copper surface is cleaned to remove any dirt, grease, or oxide and a thin film of a photo-sensitive resin is applied and allowed to dry. Subsequently, the photo-sensitive resin (called photo resist) is exposed to ultraviolet light through a negative of the wiring pattern desired. The areas of the photo resist that are exposed to the light cross-link and become insoluble in a developer, while the unexposed resist, that is, the areas of resist which were masked off from the light by opaque areas of the negative, wash away. At the conclusion of the developing stage, a plate is obtained on which some areas of copper are exposed and other areas are protected by resist. In figure 3b the plastic has been dyed to make it easier to distinguish between plastic and copper. The plate is next placed in a ferrite chloride etching bath where the exposed copper is eaten away, leaving only the desired wiring, as shown in figure 3c. The resist remaining on the wiring is removed after etching. The board is then drilled, and components are inserted and soldered in place (figures 3d and 3e).

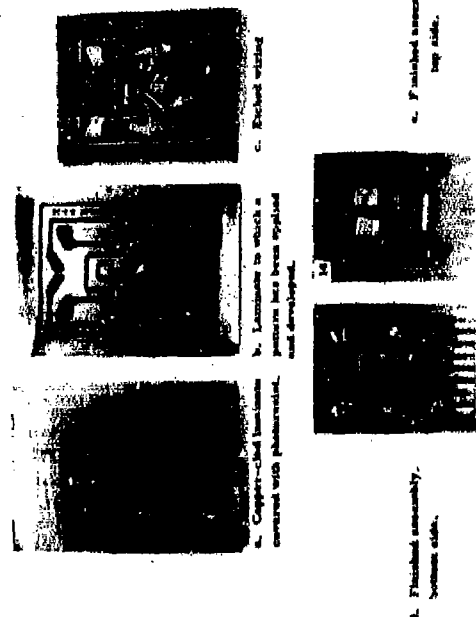
Further miniaturization was next achieved using techniques developed in DOFL prior to the year 1955. Figure 4 shows the resultant package 3/ which utilized printed wiring, printed resistors, and titanate wafer capacitors. It too, required only 10 milliwatts of power but occupied a volume of only 1/2



Components per cubic inch: 7
Volume, cubic inches: 2
Power, watts: 2

1-INCH CUBE

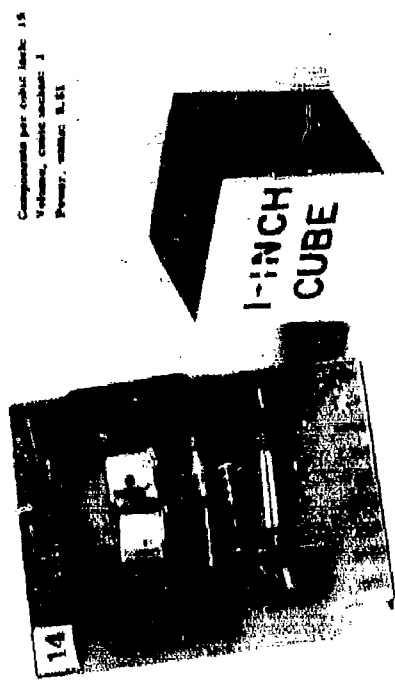
Figure 1. Binary counter stage built with a vacuum tube and standard components.



a. Finished assembly, bottom side.

b. Finished assembly, top side.

Figure 3. Seven stages of preparation of an etched wiring board.



Components per cubic inch: 15
Volume, cubic inches: 1
Power, watts: 0.55

1-INCH CUBE

Figure 4. Transistorized binary counter stage employing standard components and etched wiring board. Wiring on reverse side of board.



Components per cubic inch: 20
Volume, cubic inches: 0.5
Power, watts: 0.55

1-INCH CUBE

Figure 5. Transistorized binary counter stage employing printed wiring, printed resistors, standard washer capacitors, and standard 1-transistor and diodes.

cubic inch. This one-cubic-inch encapsulated assembly contained two binary counter stages, one on each side of the plate.

Figure 5 shows in more detail the steps required to produce the assembly shown in figure 4. The base for the printed assembly was a steatite ceramic wafer (figure 5a). The wiring pattern, figure 5b, was applied using silver paint squeezed through a "silk" screen. The wafer was then placed in an oven and fired for 1/2 hour at 700°C (1292°F). Next, the resistors were printed in the proper position on top of the wiring, as shown in figure 5c. The resistors were printed with an ink^{4/} composed of solvent, carbon, resin, and curing agent and they were subsequently cured for 3 hours at 150° C. Next, rectangular wafer-type barium titanate capacitors were sweat-soldered at the appropriate positions. The transistors and diodes were soldered in place next and the resultant assembly is shown in figure 5d. Silver-saturated solder was employed for all connections. Such solder is necessary in order that the silver wiring will not dissolve in the solder eutectic. Finally, pins and lead wires were attached and the assembly was encapsulated (see figure 5e).

The latter two packages, the etched and printed modules shown in figures 2 and 4, respectively, represented the state of the art in these laboratories, and in some of the industry, up until 1955 when general packaging work in these laboratories was temporarily discontinued. However, etched wiring continued to gain considerable favor in the fuze laboratories of DOFL in the next few years. The research group gave aid to hardware projects in circuit layout, choice of laminates^{5/}, short-cut designing, and even the postforming^{6/} of circuit boards to conform to particular fuze structures.

MICROMINIATURIZATION BY NEWLY DEVELOPED COMPONENTS AND TECHNIQUES

During the last few months, extremely miniaturized component parts have become available on the commercial market. Figure 6 shows tantalum-wire electrolytic capacitors^{7/}, tiny glass-encased diodes, 1/10-watt resistors^{8/}, ^{9/}, ^{10/}, and microminiature transistors. Utilizing these components, the binary counter, last shown in packaged form in figure 4, was reassembled and is shown in figure 7. This circuit required by 2 milliwatts of power and occupied a volume of only 1/10 cubic inch. The power reduction was accomplished by utilizing newer lower voltage circuitry. To some extent the size reduction was also traceable to the lower voltage circuitry, because lower voltage ratings on the components enable them to be produced in smaller sizes. Presumably, 10 binary counters of this design can be packaged in one cubic inch, or 140 components per cubic inch.

These miniature components have also been employed in a free running multivibrator, a binary divider, and four logic-circuit boards interconnected to produce sequential flashing of indicator lamps. These parts are shown in the center of figure 8, laid out from left to right. This assembly is composed of 76 components and, exclusive of lamps and batteries, occupies less than a cubic inch.

However, it was evident that further miniaturization was limited by the size of these admittedly miniature components. An enlarged view of a miniature transistor is given in figure 9. The exploded view at the right-hand side of figure 9 shows the can, the header, and between them the little element that does all the work. Occupying about one-hundredth of the total volume of the transistor, the tiny germanium element is the only essential part as far as the circuit is concerned. The header simply provides convenient leads and, together with the can, hermetically seals the germanium from contamination. A close examination of other components in the circuit showed a similar startling waste of space and not only suggested use of uncased crystals of germanium but also reemphasized the importance of other previously developed uncased components, especially printed wiring and printed components.

Because of their negligible thickness, printed resistors occupy a minimum of volume. Capacitors have been produced from reduced titanate formulations that yield extremely high capacitances in small volumes. For example, a 0.01 μ f capacitor has been produced in a size 0.1 inch by 0.1 inch by less than 0.01 inch in thickness.

These components, and transistors and diodes composed only of germanium wafers, were combined in the package shown in figure 10 using vacuum deposited aluminum inter-connection wires ¹¹. This design, dubbed the DOFL-2D design because of its almost 2-dimensional geometry, has a volume of only 0.005 cubic inch. Therefore, assuming no volume-waste in inter-connection of stages, 200 binary counters can be packaged in one cubic-inch, or 2800 components per cubic inch.

The steps of preparation of the DOFL-2D binary counter stage are shown in figure 11. A steatite ceramic wafer was cut to size (0.5 inch x 0.5 inch x 0.02 inch) and notched along one edge (figure 11a). This wafer serves as the baseplate for the circuit. A silver wiring pattern was next screened on the wafer and fired for 1/2 hour at 700°C (figure 11b). Using a taped mask, holes for the diodes and transistors and grooves for the capacitors were sandblasted into the wafer (figure 11c). Next, resistors were screened in place and cured for 1/2 hour at 250°C (figure 11d). Resistors having resistances out of tolerance were adjusted by heating or abrading, de-

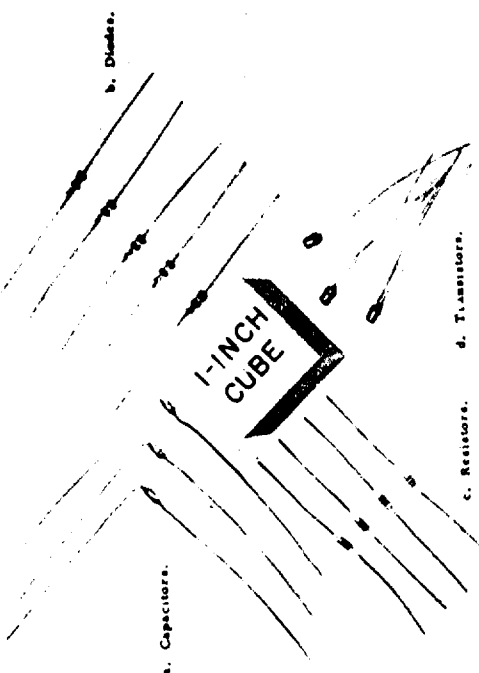


Figure 6. Commercially available ultraminiature capacitors, diodes, resistors, and transistors.

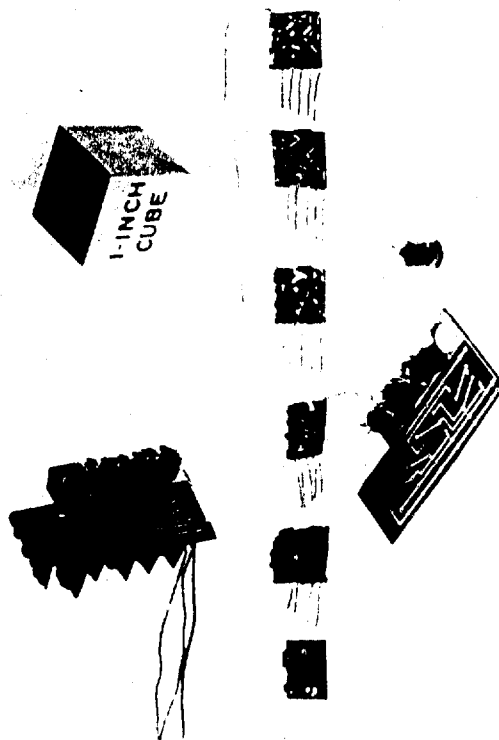


Figure 8. - Assembly (top, left) for sequential flashing of indicator lamps. employs ethyl diode connection bus (d foreground) and the following individual stages (left to right in the center): multivibrator, binary counter, and four logic circuits.



Figure 5. Steps of preparation of printed binary counter stage.

Components per cubic inch: 140
Volume, cubic inches: 0.1
Power, watts: 0.002

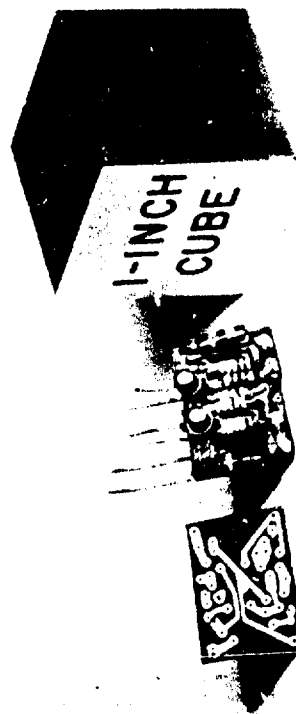


Figure 8. - Assembly (top, left) for sequential flashing of indicator lamps. employs ethyl diode connection bus (d foreground) and the following individual stages (left to right in the center): multivibrator, binary counter, and four logic circuits.

Components per cubic inch: 2800
Volume, cubic inches: 0.003
Power, watts: 0.002

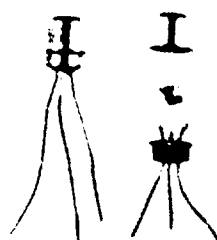


Figure 9. Ultraminiature transistor (left) and exploded view (right).

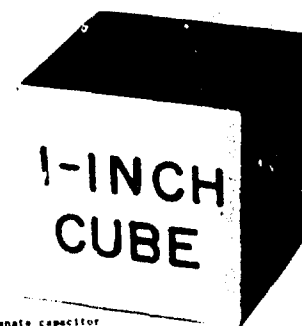
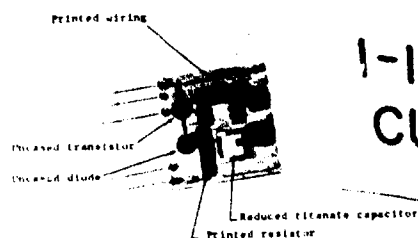


Figure 10. Wafer binary counter stage employing printed wiring, printed resistors, reduced titanate capacitors, and unbiased transistors and diodes.

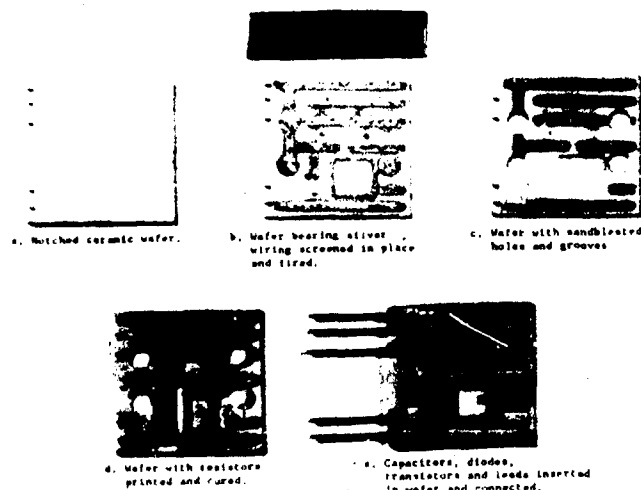


Figure 11. Steps in preparation of wafer binary counter stage.

pending on whether they were too high or too low in value. Finally, the transistors, diodes, and capacitors were inserted into the wafer and potted in place with an epoxy casting resin. Using a suitable mask, leads were vacuum deposited between the transistor-and-diode electrodes and the silver wiring. Other electrical connections were made either by vacuum deposition of metal or with an epoxy-silver flake conductive plastic ^{12/}. Lead wires were attached to the wafer and wiring with this same conductive plastic. The plastic was cured for about 1 hour at 100°C. The finished binary counter is shown in figure 11e.

DISCUSSION

The type of design which was shown in figure 7, and which utilizes miniature commercial components, should be considered in future development immediately, especially when rigorous volume specifications occur. The problems that still exist in this package include methods of soldering and techniques for interconnecting the very small stages into one compact assembly. The tip of a soldering iron is larger than many of the solder junctions on the circuit board and solder-bridging between closely spaced conductors is hard to avoid. Dip-soldering techniques ^{13/} are being investigated and refined, and methods for interconnecting etched wiring boards with minimum waste of space are being developed. A prediction of commercial production of these tiny assemblies within two years does not seem at all out of line.

A five-year prediction is made for production-line assembly of the little wafer modules shown in figure 10. Here, the problem of protective coatings which will not poison the germanium, which comprises the transistors and diodes, is paramount. Techniques for reproducibly laying down resistors of minute geometries, and producing dielectric bodies which will yield a wide range of capacitance values, are also required. A large area still requiring research is the field of microminiature magnetic components. The circuits on which efforts have been concentrated so far are of the RC variety.

In a separate report, Prugh ^{14/} has summarized recent efforts in micro-miniaturization in all DOFL 50 areas.

FUTURE WORK

Future work on microminiature packaging will include investigations of (1) the relationship between geometry of minute printed resistors and their resistance values, (2) soldering techniques which will produce excellent solder joints without bridging of conductors on microminiature circuit boards, or subjecting the components to excessive heat, (3) fabricating techniques for producing minimum-volume inductive components as flat wafers, and (4) interconnection techniques for connecting microminiature stages into larger assemblies with minimum expenditure of volume.

ACKNOWLEDGEMENTS

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